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Low frequency variability in the lower St. Lawrence Estuary

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ABSTRACT

The lower St. Lawrence Estuary is a good example of wide estuaries with a second lateral boundary within several internal Rossby radii. We compare direct measurements from the 1979 lower St. Lawrence estuary mesoscale current meter array with satellite thermal images observed during the same period. The current field appears to show two quasi-steady states: one configuration is characterized by strong outflow along the north shore of the estuary with a transverse front at the mouth. The other current pattern is more typical of estuaries, with inflow along the north shore and outflow along the south shore. Transitions between these configurations are likely to be due to instability of the current field.

1. Introduction

The lower St. Lawrence Estuary (LSLE) is a 200 km long channel which increases in width from 24 km at the western limit to about 50 km at Pointe-des-Monts where it opens into the Gulf of St. Lawrence (Fig. 1). Since the 1963 Pointe-des-Monts direct current measurements made by Farquharson (1966), and the 1965 current survey near Rimouski (Forrester, 1967, 1970), it has been realized that the LSLE is not an ideal or typical estuary: the buoyant outflow is not always confined to the right-hand side of the estuary (when looking downstream). Farquharson (1966) reported the presence of a predominantly southward flow at the mouth of about 20 cm s^{-1} near the surface and suggested that there is an anticyclonic eddy in the LSLE, with its center somewhere between the Pointe-des-Monts and Rimouski sections. He found further evidence for the existence of such an eddy from the path followed over a 5-day period by a parachute drogue set to drift at a depth of 75 m.

The presence in the Rimouski section of a northward residual cross-channel current of 7 cm/s was first reported by Forrester (1967) who further noted that "the outflow above 50 m in that region appears to be almost equally strong along both shores, and weakest in the middle." This is a departure from the ideal two-layer estuary. The presence of the northerly cross-channel residual current near Rimouski was also

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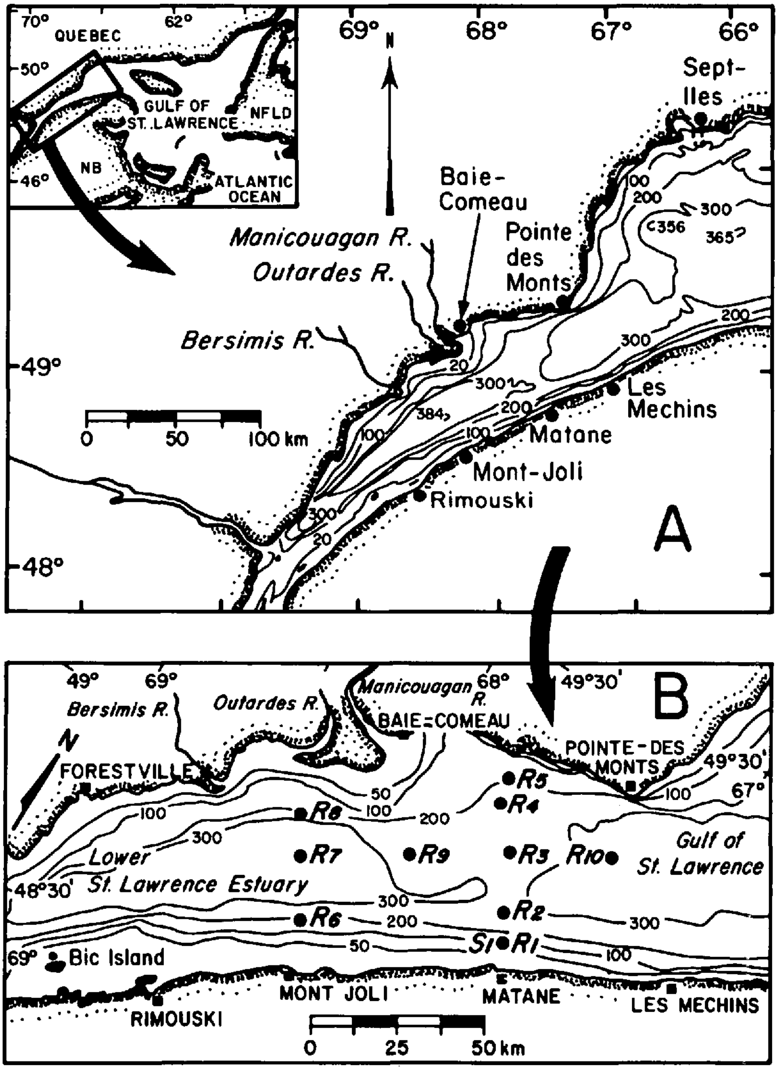

Figure 1. (a) Map of the study area; (b) Locations of the 1978 and 1979 current meter moorings in the lower St. Lawrence Estuary.

confirmed by Murty and El-Sabh (1977) and El-Sabh (1979) who placed a parachute drogue at 10 m depth near Bic Island on the south shore during calm wind conditions and recovered it 32 hrs later near Forestville on the north shore. Furthermore, on several occasions, distributions of surface salinity, temperature, density and chemical parameters near the Bic Island—Rimouski region were reported to veer toward the north shore as shown in Figure 2 (Neu, 1970; El-Sabh, 1977; Kranck, 1979; Bewers and Yeats, 1979). Recent current measurements taken in 1979 in the area between Mont-Joli and Pointe-des-Monts (Fig. 1b) also show the mean circulation in the upper

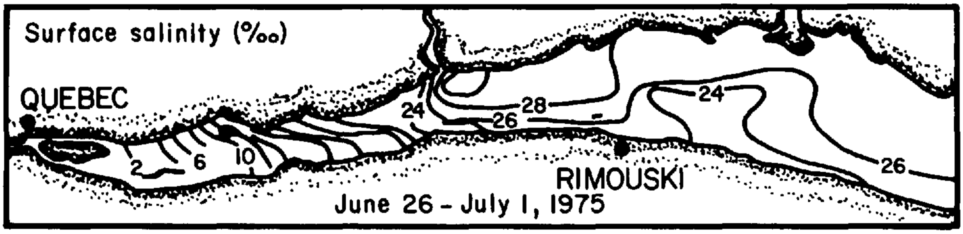

Figure 2. Surface salinity plot observed in the St. Lawrence Estuary during the period June 26 to July 1, 1975. Contour interval is 2 ‰ (modified from Kranck, 1979).

30 m to be characterized by two coastal currents flowing seaward parallel to both shores, and a southward cross-channel flow at the mouth of the LSLE (Koutitonsky and El-Sabh, 1985).

The southward cross-channel flow at the mouth of the LSLE detected by several authors (e.g. Farquharson, 1966; El-Sabh *et al.*, 1982; Koutitonsky and El-Sabh, 1985) was found to correspond to strong along-channel density gradients (Tang, 1980a; 1983) as would be expected on geostrophic grounds. Essentially, Tang found a density front at the mouth of the LSLE, referred to here as the Pointe-des-Monts front, separating estuarine and Gulf waters; Figure 3a shows an example of the thermal signature on the front.

The LSLE is a good example of an estuary with moderately high Kelvin number, using Garvine's (1986) classification scheme. The Kelvin number is the ratio of the width of the estuary to its internal Rossby radius

$$\lambda_R^2 = g h_1 \Delta\rho \rho^{-1} f^{-2}$$

where h_1 is the thickness of the upper layer and $\Delta\rho$ is the density difference between the upper and lower layers. For the LSLE, $\lambda_R \simeq 10$ km (Lie and El-Sabh, 1983; Mertz *et al.*, 1988b) so that the Kelvin number lies in the range 3 to 5. As Garvine (1986) notes, estuaries with large Kelvin numbers are strongly influenced by Coriolis effects. Thus, the outflow tends to be trapped within a Rossby radius of the coast (the south shore here) implying the presence of strong vertical and lateral shears. These shears may promote instability. In an estuary with a moderately large Kelvin number, unstable waves may be able to interact with the second lateral boundary. This feature makes the LSLE interesting, particularly since we can clearly document the presence of unstable waves here (El-Sabh, 1988; Lacroix, 1987; Lavoie *et al.*, 1985; Mertz *et al.*, 1988b). It is not unusual to find "backward-breaking" waves (in the terminology of Griffiths and Linden, 1981) distorting the front between offshore waters and the cold water sometimes present along the south shore of the LSLE (Fig. 3b). A backward-breaking wave is an asymmetric dipolar disturbance in which the anticyclonic zone wraps around a cyclonic vortex to form a crested streamer pointing upstream ("backwards").

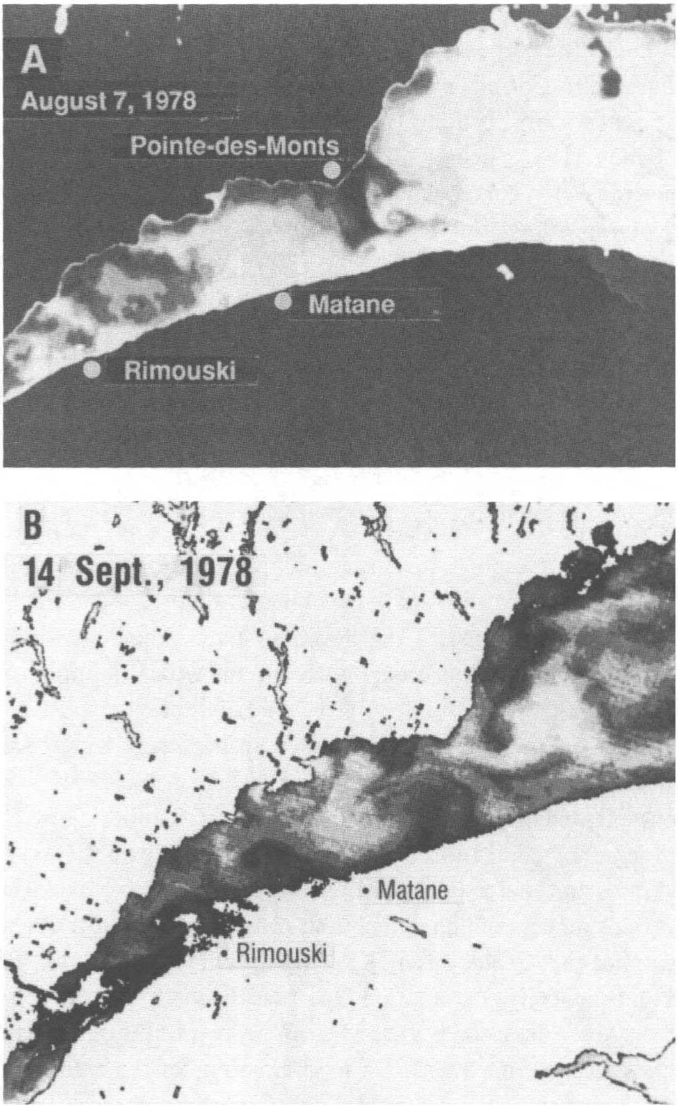

Figure 3. HCMM Satellite infrared thermal images observed in 1978 showing: (a) the cold Pointe-des-Monts front and (b) typical pattern of unstable waves in the lower St. Lawrence Estuary (modified from Lavoie *et al.*, 1985). Darker areas indicate colder water. For reference, note that the distance between Rimouski and Matane is about 100 km.

Historical evidence, listed earlier, and data that we present in the next two sections seem to show that current meanders of the south-shore outflow can grow to large amplitude and attach to the north shore. They may stick there due to the Coanda effect. Carstens *et al.* (1984) describe this effect in terms of lateral entrainment. A river plume will be drawn toward a coast and tend to attach there. This could lead to the formation of a north shore jet when a meander encounters this coast. The resulting north shore jet meets the corner at Pointe-des-Monts (Fig. 1) detaches from the coast and turns right (due to Coriolis effects) and after crossing the mouth of the estuary attaches to the south shore forming the root of the Gaspé Current (El-Sabh, 1976; El-Sabh and Benoit, 1984; Benoit *et al.*, 1985; Lacroix *et al.*, 1985). This would account for the transverse current found by Farquharson (1966, about one month of data) and the corresponding transverse front separating freshened estuary waters and saltier Gulf waters detected by Tang (1980a; 1983). We will show that this transverse front is probably unstable. Using the 1979 mesoscale current meter array, we will present evidence indicating that the front may develop large deformations, characterized by periods of inflow from the Gulf. We will conclude that the LSLE shows two quasi-steady states, the first characterized by outflow along the south shore and inflow along the north shore (a typical estuary), the second showing outflow along the north shore with a strong transverse front at the mouth of the LSLE. We suggest that flips between these two configurations are mediated by unstable wave motions.

2. The LSLE during summer 1979

In this section, we will compare the low-frequency circulation of the LSLE, as determined from the 1979 current meter observations with satellite observations and show that changes in the current pattern are probably due to unstable wave activity. Before proceeding, we again emphasize that the LSLE is a high Kelvin number estuary and thus one may expect quite complex behavior of the current field.

In 1979, a mesoscale current meter array program was undertaken in the LSLE to resolve the presence of eddies and transverse currents previously reported to exist there. Aanderaa current meters were moored simultaneously at 10 stations, $R_1 - R_{10}$ (Fig. 1b), at various depths and during periods of time lasting from one to six months. The experiment and the surface residual variability were described by El-Sabh *et al.* (1982). Other aspects of the circulation, as determined by the 1979 program, were discussed by Lie and El-Sabh (1983), Koutitonsky (1985) and Koutitonsky and El-Sabh (1985). Here, we are interested in the low frequency circulation and thus we calculate 15-day averages of the currents at each near-surface sensor and plot them in Figure 4 (the tidal signals were removed before averaging). Table 1 gives the instrument depth for each station and the mean current for the entire record. Mertz *et al.* (1988a) have shown that the along-channel winds and currents at station R_{10} are coherent in the 10–15 day period band. The averaging will substantially reduce the meteorologically-induced variability and allow us to focus on the longer time scale circulation. Strong transverse currents are clearly apparent; their strength and position changes in time, highlighting the low frequency variability.

Since we are discussing low frequency variability, we must note that the freshwater runoff cycle contributes a long period change, particularly in the salinity record. In Figure 5, we show time variation of the St. Lawrence River outflow at Québec for

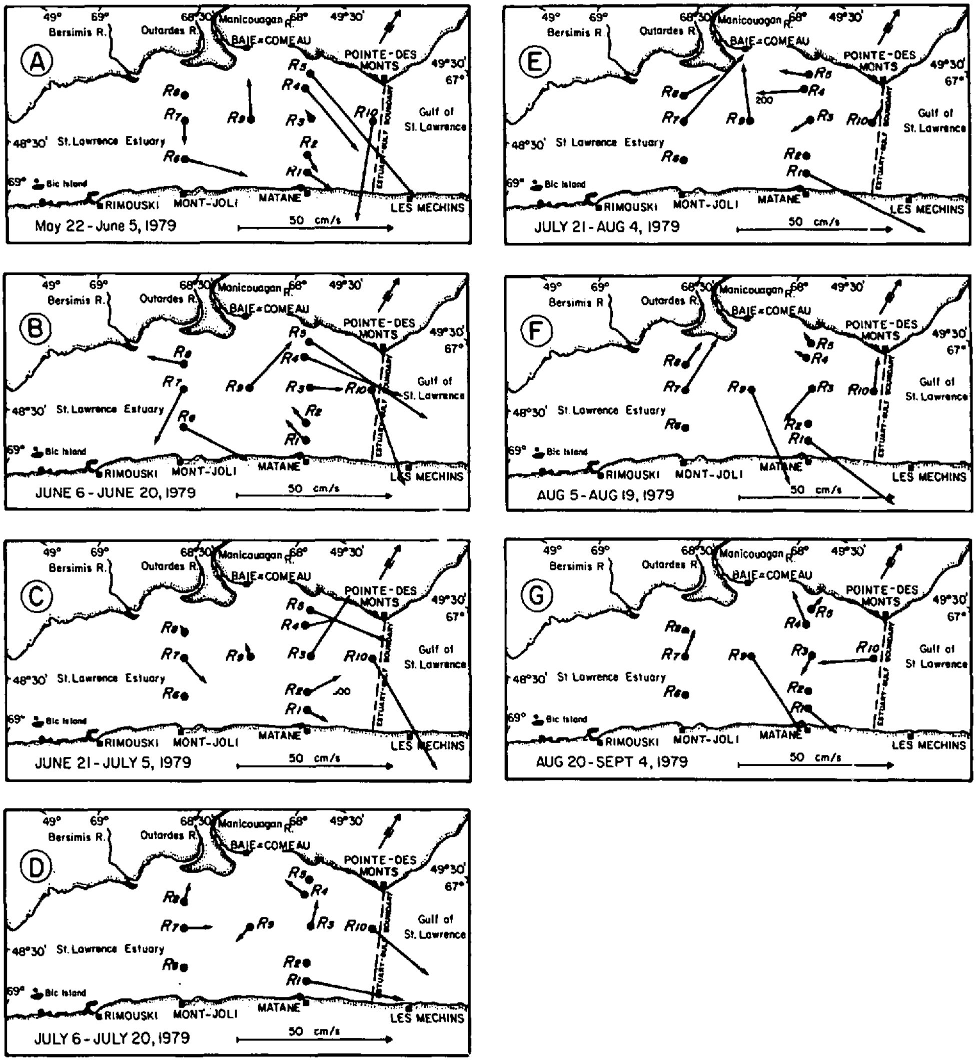

Figure 4. 15-day averages of the currents measured during the 1979 LSLE array program.

1979, amounting to about 80% of the total freshwater input to the LSLE (El-Sabh, 1979, 1988; Koutitonsky, 1979). There are additional inputs from the Saguenay River and Manicouagan-Outardes Rivers on the north shore. These rivers are regulated and do not discharge with a seasonal cycle. Note that the LSLE is largely ice-free by early April (El-Sabh, 1979) and thus ice melt is excluded as a source of fresher water in late spring. Figure 6a shows the salinity record from R_9. One cannot definitively identify the salinity minimum, but it appears to have occurred in late May, about one month after the runoff maximum. Tee and Lim (1987) developed a two-dimensional (vertical-longitudinal) model for the St. Lawrence system and found that the salinity

Table 1. Instrument depths and mean speeds in cm s^{-1} of the near surface sensors for each current meter mooring observed during 1978 and 1979 in the lower St. Lawrence Estuary. U = along-channel (positive downstream), V = cross-channel (positive northward). See Figure 1b for mooring locations.

Station	Instrument depth (m)	Year	Record length (days)	U	V
				(cm/s)	
S_1	24	1978	62	−02.5	−0.2
R_1	17	1979	110	16.2	−7.8
R_2	11	1979	46	02.6	1.5
R_3	18	1979	118	02.6	0.3
R_4	10	1979	105	04.7	−3.8
R_5	9	1979	103	13.2	−10.2
R_6	10	1979	32	19.8	−8.2
R_7	28	1979	108	5.7	2.0
R_8	12	1979	88	0.4	3.8
R_9	10	1979	125	4.9	−2.2
R_{10}	7	1979	115	4.7	−15.5

minimum in the LSLE lags the runoff maximum from the St. Lawrence River by about one month, in approximate agreement with the 1979 data. In this paper, we will focus on a rapid transition in the flow field of the LSLE, which occurred around mid-July 1979. This event is apparent in Figures 4 and 6b, c, d, e. This change, the center of the discussion to follow, is quite abrupt in contrast to the slow variations associated with the seasonal cycle.

Figure 7 shows drawings from satellite thermal images of the LSLE during summer 1979. The contrast of the original images was generally low, thus precluding ready reproduction and we have elected to the present mesoscale features captured in the

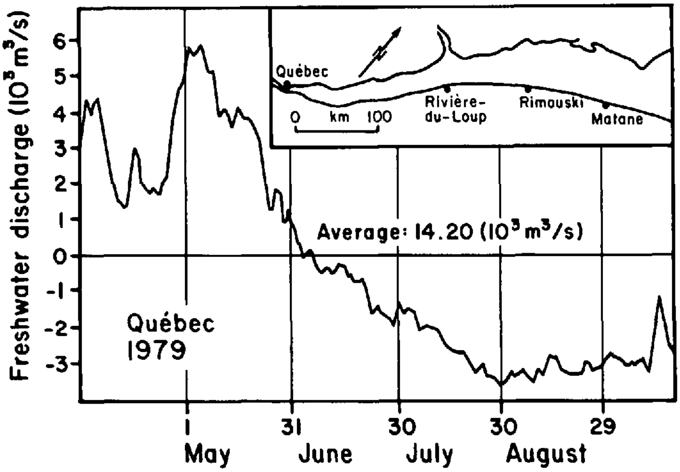

Figure 5. Freshwater discharge from the St. Lawrence River in 1979.

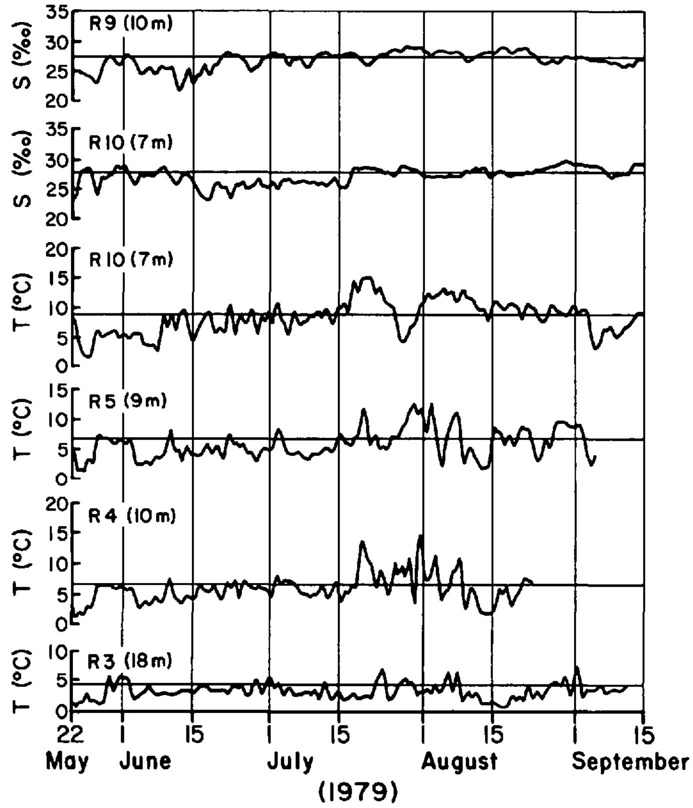

Figure 6. Salinity and temperature time-series records observed in the LSLE during 1979 (see Fig. 1b for station locations).

images as drawings. The line (in the estuary) depicts the front between cool waters often found along the south shore of the LSLE and warmer offshore waters. The front is not a permanent feature and its intermittent appearance combined with a substantial number of cloudy days during summer in this region make it difficult to trace the circulation with thermal imagery. There were clear wave or loop-like disturbances of the front during three episodes: June 17–21, August 3–9, and August 16–26. In Figure 7, we have reproduced eight of the ten images from these periods indicating disturbance activity. There is an encouraging correspondence between Figure 4 and Figure 7. In Figure 4e, f, g, there appears to be a loop in the current near Baie-Comeau (sensors R_7, R_8, R_9), particularly in Figure 4f. Figure 7 (d, e, f, g, h) shows that from August 2 to August 26, there was a bulge in the front near Baie-Comeau. This bulge may indicate the presence of a wave or meander in the south-shore jet which is quasi-steady.

Prior to early July (Figure 4a, b, c), a current pattern featuring strong transverse

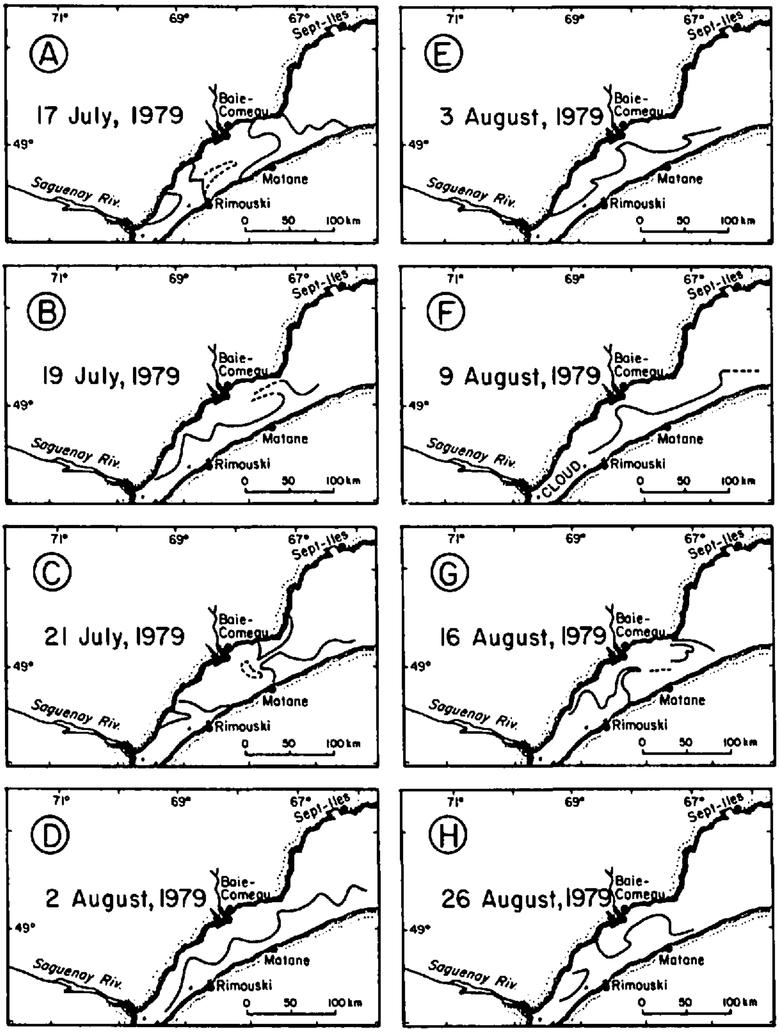

Figure 7. Drawings of mesoscale features observed in satellite thermal images of the LSLE during summer 1979. The line in the estuary demarcates the boundary between cool water along the south shore of the LSLE and warmer water offshore.

flow near the mouth (station R_{10}) of the LSLE is clearly evident. The flow at R_1 is weak, contrary to one's expectation that a strong south shore jet should be present. The currents at R_4 and R_5 indicate that a strong north-shore jet exists and it apparently crosses the estuary at the mouth and attaches to the south shore. As noted in the introduction, Tang (1980a, 1983) has reported a transverse front at the mouth of the LSLE, between freshened estuary waters and saltier Gulf waters. It is during these conditions of strong lateral flow (Fig. 4a, b, c) when we expect this front to be present.

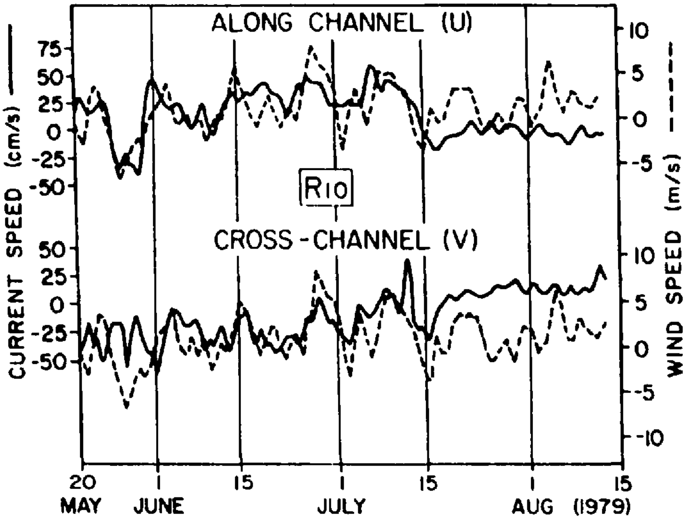

Figure 8. Observed subtidal currents at station R_{10} in 1979 plotted with the along-channel wind at Baie-Comeau. The current records have been advanced two days.

A steady baroclinic current setting across the mouth requires a lateral density gradient to balance the Coriolis term. We can infer that the transverse front was present from late May to late June 1979.

Examination of Figure 4c, d, e conveys the impression that the flow field underwent a major transition around mid-July. In Figure 4d, the flow field is dominated by a south shore jet (R_1) and in Figure 4e, the loop discussed earlier in this section appears to have formed. Further evidence of this transition may be seen in Figure 8. We have plotted currents at station R_{10} with the along-channel winds from Baie-Comeau. Prior to about July 15, the along-channel flow exhibited a strong mean and large fluctuations coherent with the wind. After this date, the mean is small and the fluctuations are very weak. A similar change is apparent in the cross-channel flow. It seems likely that the wind driven fluctuations were frozen into the current as it flowed along the north shore and were advected past the sensor at R_{10}. When the flow pattern shifted in mid-July, the mean flow no longer passed through R_{10} and fluctuation energy dramatically dropped. This change of behavior is in accord with the changing pattern seen in Figure 4, which shows a flipping of the mean flow from a path along the north shore (and then across the estuary) to a trajectory along the south shore. Inspection of Figure 7 shows evidence of some type of activity near the mouth from July 17 to 21, which may relate to the transition.

The salinity and temperature records shown in Figure 6 lend further credence to the idea that a transition occurred. As noted earlier, the salinity record from station R_9 (Fig. 6a) shows a smooth seasonal signal and is unaffected by the mid-July event. This is typical of most of the measurements taken in 1979. However, the salinity and temperature records at R_{10}, R_4 and R_5 clearly show a rapid change around mid-July, as seen in Fig. 6b, c, d, e. At R_{10} a jump in salinity and temperature is visible just after July 15, and the temperature record in particular shows a large oscillation just after the transition. Especially interesting are the temperature records from R_4 and R_5 which demonstrate a pronounced increase in mean temperature, with large fluctuations after the mid-July event. The increase of salinity and temperature at R_{10} is consistent with the flow pattern, indicating a tongue of Gulf of St. Lawrence water moving along the north shore of the LSLE. Stations R_4 and R_5 apparently lie near the terminus of this tongue, and the enhancement of thermal variability may reflect frontal oscillations, or perhaps the formation of small-scale intrusions here, at the end of the tongue. Figure 6f shows an indication of similar behavior at station R_3.

To summarize these observations, we offer the following description: prior to mid-July, the flow field was dominated by strong currents through R_3, R_4, and R_{10}. Apparently a north-shore jet was present, which separated from the coast and formed a transverse current near the Pointe-des-Monts section. The north-shore outflow is contrary to the ideal estuary case; this flow may have resulted when a current meander attached to the north shore. The south to north leg may pass through R_9 in Figure 4a, b, whereas Forrester (1967, 1970) and El-Sabh (1979) found a northward transverse current in the Bic-Rimouski area. Near mid-July the flow pattern dramatically changed. The strong transverse flow near the mouth of the LSLE disappeared and the flow field exhibited a configuration more typical of estuaries. The formation of the loop near Baie-Comeau may represent an unstable mode of the south-shore jet excited by the transient motions resulting from the transition occurring earlier.

We will show in Section 4 that the Pointe-des-Monts transverse front is unstable and was probably the agent responsible for the flipping of flow patterns. From about July 7–12, the along-channel winds (Fig. 8) were moderately strong and Gulfward. Under these conditions upwelling of deeper cold water may develop near Pointe-des-Monts (Lacroix, 1987). This is in accord with the presence of cold water near this location on July 17 (Fig. 7a). We propose that the appearance of dense water here provides an initial perturbation of the front, which then grows due to instability.

Chia *et al.* (1982) have discussed the interaction of unstable waves with boundaries. Figure 9a, b, c is redrawn from their Figure 6 and depicts an unstable wave growing and contacting a coast, a type of interaction they observed in their laboratory experiments. Note that the front is longitudinal here (shaded areas represent denser water, unshaded lighter water). When the wave meets the coast an intrusion propagates along the coast with its flow right-bounded. This in accord with the propensity of buoyant flows to move with the boundary on their right due to Coriolis effects.

Figure 9d, e, f shows how a wave developing on the Pointe-des-Monts transverse front at the mouth of the LSLE might be affected by the coast. The initial wave (Fig. 9d) steepens (Fig. 9e) and finally forms an intrusion (Fig. 9f). Note that for a

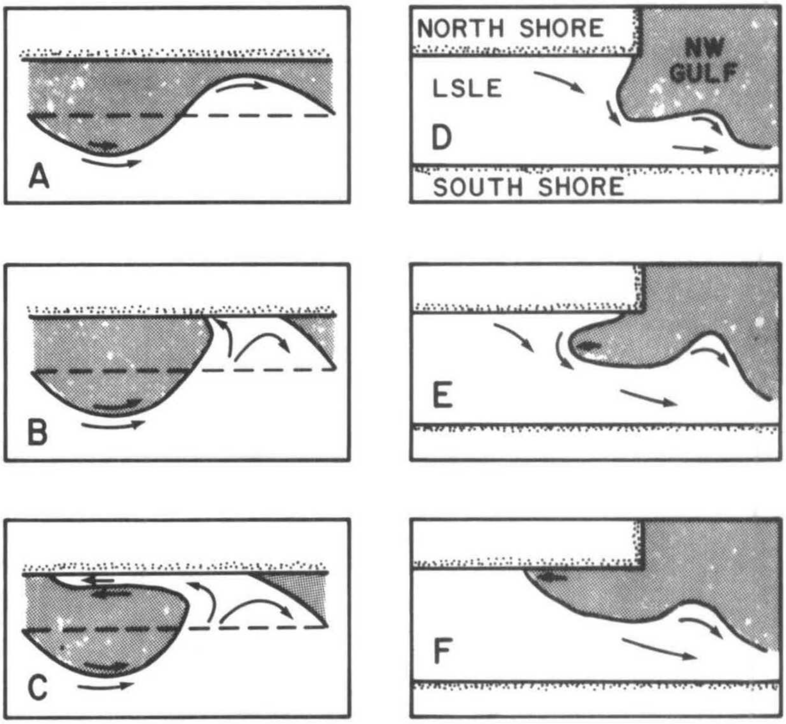

Figure 9. (a) through (c): The interaction of an unstable wave with a boundary (redrawn from Chia *et al.*, 1982). (d) through (f): Conceptual depiction of the interaction of an unstable wave growing on the Pointe-des-Monts transverse front with the north shore of the LSLE.

dense intrusion to propagate with the boundary on its right, it is necessary that the Coanda effect play a role. The influence of Coriolis effects alone would yield a left-bounded intrusion of dense water. Such a left-bounded intrusion would be possible along the south shore of the LSLE, and indeed, in the next section, we will present evidence suggesting that such intrusions do occur.

The data we have presented do suggest that an intrusion of Gulf water along the north shore did occur. One can say definitely that the Pointe-des-Monts front between Gulf and Estuary water shifts, based on Figures 4 and 6. This transition may be due to instability of the Pointe-des-Monts front. In Section 4, we will discuss the stability properties of the frontal jet, and show that instabilities with wavelengths in the range 50 to 80 km are likely to develop in the Pointe-des-Monts front at the mouth. Thus the mechanism sketched in Figure 9 is possible. We envision that the flow field may persist in the pattern shown in Figure 4a, b, c until a large amplitude unstable wave develops at the Pointe-des-Monts front. The instability causes the circulation to flip into the typical estuarine pattern with inflow along the north shore and outflow along the south shore.

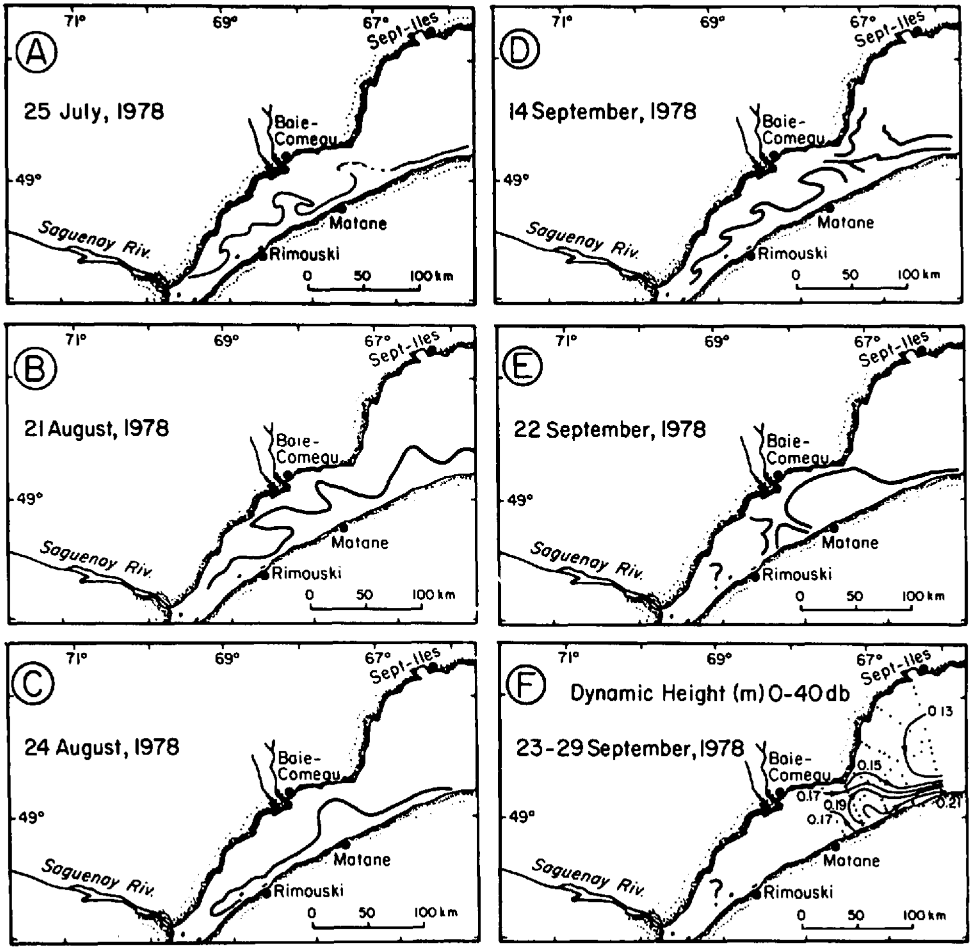

Figure 10. Drawings of mesoscale features observed in satellite thermal images of the LSLE during summer 1978. The line in the estuary demarcates the boundary between cool water along the south shore and warmer water offshore. Figure 11f is the dynamic topography near the mouth region modified from Tang (1980a).

3. The LSLE during summer 1978

Summer 1978 was an excellent season for observation of unstable waves in the LSLE, via satellite thermal imagery. A discussion of these wave episodes and their relation to baroclinic and barotropic instability may be found in Mertz *et al.* (1988b). Here we have reproduced several images from summer 1978 as drawings in Figure 10. The heavy line in each of the drawings (Fig. 10a, b, c, d, e) again demarcates the boundary between warm water offshore and cool water often found along the south shore of the LSLE. Figure 10f is the surface dynamic topography for 23–29

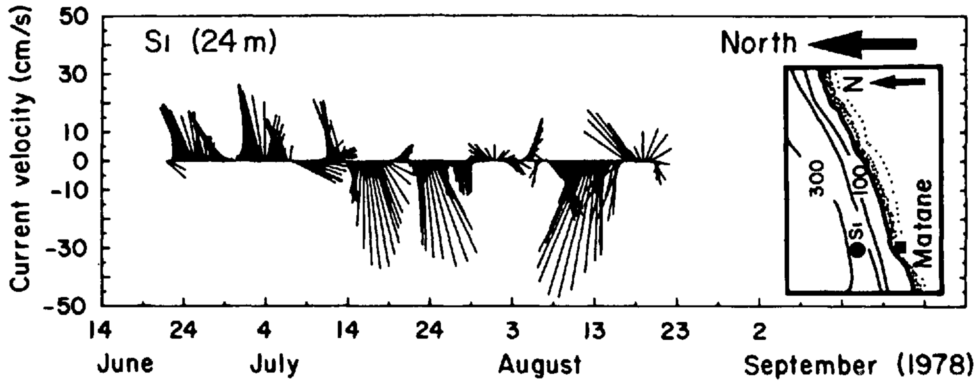

Figure 11. The subtidal current record from station S_1 off Matane.

September, reproduced from Tang (1980a). Figure 10a, b, d records three instances of backward-breaking waves reported by Mertz *et al.* (1988b) for summer 1978. In Figure 10c, e, the frontal distortion may indicate the presence of a loop; Fig. 10f clearly shows a loop near the mouth of the LSLE. It is clear that the same general patterns of thermal variability occurred in both 1978 and 1979 each summer.

There was no moored array program during 1978 but we are fortunate to have one current meter record from summer 1978 (station S_1 as indicated in Fig. 1b) from the same site as R_1 of the 1979 program. It was anticipated that the near surface sensor of station S_1 (24 m) would detect the south shore jet; in fact, the along-channel mean flow reported was -2.5 cm s^{-1} (Table 1). The record from S_1 (24 m) is shown in Figure 11. In contrast, at R_1 (depth = 17 m) observed in 1979 at the same location, a mean along-channel flow of 16.2 cm s^{-1} was recorded (Lie and El-Sabh, 1983). Figure 11 shows a curious pattern of variability: there appears to be a weak Gulfward mean flow present until early July; after this time, the flow is predominantly up-estuary (there are three large upstream pulses in the periods: July 14–19, July 22–26 and August 7–14). The wind record shows only one strong event during this period: a Gulfward pulse from about August 6–14 (directed oppositely to the current event during this interval). Figure 10a shows the thermal structure for July 25, 1978 showing backward-breaking waves present upstream of S_1, indicating that there was a Gulfward mean flow along the shore prior to this date, although at S_1 the flow was essentially upstream from July 14 onward.

In this section, we offered a discussion of how the upstream pulses might have developed due to an unstable wave growing in the transverse segment at the mouth. We hypothesize that the formation of such intrusions is a process which could yield upstream pulses. It is also possible that these events are due to the pinching off of an anticyclonic eddy from a loop such as that seen in Figure 10f. If the eddy interacted and merged with the mean flow, an upstream pulse would result.

4. Discussion

There appears to be an ample body of evidence to establish that a persistent transverse current is sometimes present near the Rimouski section of the LSLE: Forrester (1967) reports a significant northward cross-channel current at the Rimouski section (approximately one month of data); Murty and El-Sabh (1977) and El-Sabh (1979) verify its presence by tracking near-surface drifters. Analysis of the 1979 data (El-Sabh *et al.*, 1982 and present study) showed laterally-directed currents through stations R_9 and R_7 enduring for about one month (Fig. 4e, f). An important consequence of this transverse flow in the body of the LSLE is that it can yield a north-shore jet which in turn produces the lateral Pointe-des-Monts front at the mouth. The north-shore jet cannot follow the coastline beyond Pointe-des-Monts and thus turns south, setting across the LSLE, thereby yielding the front at the mouth.

Unstable disturbances, growing in the south shore jet, provide a possible source for lateral motions. The unstable features may take the form of backward-breaking waves or current loops; in either case significant lateral displacements of the flow (meanders) will be present. These phenomena may be quite persistent of their own accord and may become quasi-steady if a meander attaches to the north shore of the LSLE. This pattern may be disrupted by further unstable wave activity; we offered evidence suggesting that instability of the Pointe-des-Monts front at the mouth can cause a shift of flow configuration in the LSLE.

Mertz *et al.* (1988b) discussed the stability of the south shore jet. Here, we would like to briefly analyze the stability of the lateral front at the mouth of the LSLE. Figure 4a, b, c shows that strong currents are present in this zone, up to 40 cm s^{-1} (through station R_{10}). The situation differs somewhat from that of the south shore jet since the transverse jet is not bounded on its flanks. Following Mertz *et al.* (1988b) and Tang (1980b), we examine two-layer models of the system. These authors specify an upper layer thickness of $h_1 \simeq 40$ m and $\lambda_R = 10$ km, these numbers being roughly applicable to the LSLE or Gaspé Current. The authors above took the ratio of upper to lower layer thickness (δ) to be 0.2 (lower layer thickness of about 200 m).

Killworth *et al.* (1984) have presented a two-layer frontal instability model for an unbounded fluid. The necessary input parameters are λ_R and δ. The upper layer has a mean thickness that goes as $\overline{h}(y) = h_o[1 - \exp(-y/\lambda_R)]$ with y being the cross-front coordinate ($h_o = 40$ m here); this corresponds to constant potential vorticity. Figure 4 of Killworth *et al.* (1984) shows the fastest growing unstable waves (which are presumed to be preferred) for this case have a wavelength of $1.22 \times 2\pi \times \lambda_R = 77$ km. Killworth *et al.* show that their estimates of wavelength for maximally unstable waves do not differ greatly (for small δ) from those of the Phillips (1954) model, which again applies to a two-layer fluid, but without a front. The Phillips model predicts, for our numerical specifications, a wavelength of $\lambda = 1.39 \times 2\pi \times \lambda_R = 87$ km, quite comparable to the 77 km estimated above.

For completeness, we note that the Niiler-Mysak (1971) barotropic instability model predicts wavelengths of about 50 km. Mertz *et al.* (1988a) found the appropriate half-width (L) of the LSLE outflow to be about 10 km. Eq. 8 of Niiler-Mysak gives the wavelength of maximally unstable waves to be $0.81 \times 2\pi \times L = 51$ km.

The wavelengths estimated above suggest that the mechanism outlined in Figure 9 are possible; that an unstable wave trough can intrude into the LSLE. The LSLE is about 50 km wide at its mouth, this span being sufficient to accommodate at least half a wave.

To summarize our findings, we believe that we have identified two quasi-steady configurations of the LSLE. One pattern features a current field dominated by south shore outflow with north shore inflow, the classic estuarine system. In its other state there is strong outflow along the north shore and a transverse front at the mouth of the LSLE off Pointe-des-Monts. Unstable wave activity may produce the transitions between these configurations.

Future work should focus on numerical models of the buoyant outflow of the LSLE. We expect that simulations of growing disturbances in the outflow will produce many fascinating patterns of current flow in the LSLE. The 15-day averages presented here can at best crudely represent the variability. Ideally, one would like to examine the statistical relationships between the output of a numerical model and the 1979 data.

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